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SAR-Related Stress Variability in the Marine Atmospheric Boundary Layer (MABL) (HI-RES ARI)

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Long Term Goals:

By variably stressing the sea surface, secondary circulations within the marine atmospheric boundary layer (MABL) can modulate the sea–surface wave field and so can produce discernible signatures on synthetic aperture radar (SAR) images of the ocean. These microscale circulations have horizontal wavelengths on the order of one to ten times the boundary layer depth, or approximately one to ten km, and temporal scales on the order of one to ten hours. Also, the frequent occurrence of two-dimensional mesoscale atmospheric circulations in response to the sea surface temperature (SST) gradient along the northwest wall of the Gulf Stream adds an atmospheric component to Gulf Stream signatures on SAR images having cross–stream scales of 1 to 50 km. Our long-term goal is to develop methods for diagnosing both the form and the effect on sea-surface stress patterns of these buoyantly forced MABL flows, given only values of the large-scale meteorological and oceanographic parameters. As briefly summarized below, we continue to make strong progress on this problem using several interacting, complementary techniques that range from data analysis to model development.

Scientific Objectives:

Our most immediate goal is to determine how effective these two- and three-dimensional buoyantly forced MABL circulations are in producing patterns of sea-surface stress variability that can be directly linked to the quasi-linear and cellular SAR signatures that were observed during the two HI-RES ARI cruises and by satellite mounted sensors (Fig. 1). Two primary objectives must be met for us to achieve these goals. First, the surface layer structure within the MABL must be related to the sea-surface stress patterns for each of the three microscale atmospheric boundary layer convective forms: the two-dimensional mixed-layer rolls, the three-dimensional mixed-layer thermals, and the surface layer plumes, as well as for the solenoidal MABL circulation associated with quasi-linear SST gradients along the northwest wall of the Gulf Stream (Fig. 2). Second, the environmental conditions necessary and sufficient for the formation of each of these buoyantly-driven circulations must be identified.

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November 15, 1994

Dr. Dennis Trizna
Space and Remote Sensing Program
ONR 321SR
Room 704
800 N. Quincy St
Arlington, VA 22217-5660

Dear Dennis

Enclosed please find a copy of the annual report for our HI-RES grant, "SAR-Related Stress Variability in the Marine Atmospheric Boundary Layer (MABL)". This report has been submitted electronically via e-mail to Ms. Michele Mizuki as requested. Also enclosed are copies of the two figures and a transparency of the first figure, a SAR image.

If you need any additional information, then do not hesitate to contact me.

Best regards,

Hampton N. Shirer
Associate Professor and Associate Head

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Figure 1 ERS-1 SAR signatures of sea-surface roughness in the HI-RES 2 area on June 17, 1993 at 1538 GMT. Two distinct patterns of sea-surface roughness are evident within the imaged area. The first is a marbled pattern throughout the northwest portion of the image. The second is a mottled pattern throughout the southeast portion of the image. It is theorized that the mottlings are SAR signatures of sea-surface wave perturbations caused by MABL-convection-induced air/sea momentum flux patterns in a statically unstable MABL, and that the marbling is indicative of a sea surface beneath a statically stable MABL (from Sikora *et al.*, 1995)

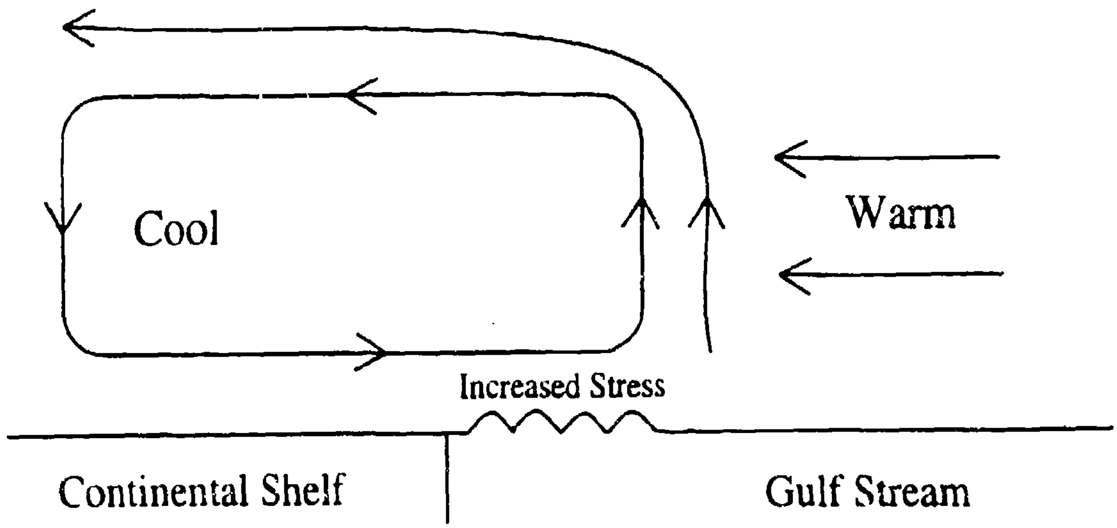

Figure 2. The Gulf Stream atmospheric frontal circulation. The sea surface temperature dictates the conditions of the MABL, creating a cooler airmass to the west and a warmer airmass to the east. A density current results, with cool air flowing along the surface from the Continental Shelf to the Gulf Stream. This flow results in a MABL convergence zone over the Gulf Stream and an area of locally high stress between the Gulf Stream North Wall and the MABL convergence zone.

Approach:

Our approach is to combine observational and modeling studies of the various secondary circulations in the MABL to determine their contributions to stress variability at the sea surface. Sikora and Young (1993, 1994) used both conditional sampling and composite analysis of atmospheric surface layer observations to describe the occurrence, structure, and sea-surface stress and wind patterns of MABL convection. SAR signatures of this phenomenon seen on an ERS-I image are being examined for one case during the second HI-RES cruise (Fig. 1; Sikora *et al.*, 1995). In addition, observations from both HI-RES cruises have been used in analyses of a somewhat larger scale, yet still buoyantly driven, flow associated with the sharp SST gradient along the northwest wall of the Gulf Stream (Sublette 1994; Sublette and Young 1994). This solenoidal flow is being studied with the Penn State/NCAR mesoscale model MM4 using conditions from the priority days of the first HI-RES cruise in Fall 1991 (Sublette 1994; Sublette and Young 1994). Finally, the stress variability produced by the microscale circulations is being studied with several new nonlinear dynamical systems, including those for stratocumulus circulations (Laufersweiler 1993; Laufersweiler and Shirer 1994, 1995), two-dimensional rolls (Bromfield 1995) and three-dimensional cells (Lambert 1995). The stress variability patterns produced by these circulations will be provided to the HI-RES wave and backscatter modelers.

Tasks Completed:

Preparation of a dynamically-based methodology for converting the planview patterns of surface stress variability caused by MABL convection into forcing fields for ocean wave and radar backscatter simulations of specific SAR images has been completed, with the results given in Sikora and Young (1993, 1994). Collaborations with several HI-RES colleagues are underway on the application of this new methodology. Thus far, this collaboration has resulted in the completion of a manuscript demonstrating the utility of ERS-I SAR to determine MABL stability and convective aspect ratios (Sikora *et al.* 1995). This work also will be submitted to the Third Thematic Conference on Remote Sensing for Marine and Coastal Environments that will be held in September 1995 in Seattle, WA.

The first set of mesoscale atmospheric simulations of the Gulf Stream atmospheric front for priority days from the first HI-RES ARI cruise in Fall 1991 has been completed using the Penn State/NCAR mesoscale model MM4. Analysis routines to diagnose the dynamics of this system and the resulting sea-surface stress field have been prepared by graduate student Sean Sublette. He presented this work at the American Meteorology Society's Sixth Conference on Mesoscale Processes (Sublette and Young 1994); it is also the subject of his MS thesis (Sublette 1994) and a journal article in preparation (Sublette and Young 1995).

The two-dimensional version of the convection model has been coded and a case study using parameter values typical of the MABL has been completed as the MS thesis project of Peter Bromfield (1994). The rewriting of the three-dimensional model originally coded by Julie Schramm has been completed and preliminary results discussed by MS student Louis Zuccarello (1994); this model is being further upgraded and its results analyzed by MS student Bruce Lambert (1995). These results will be presented at the 11th Symposium on Boundary Layers and Turbulence in March 1995 (Shirer *et al.*, 1995).

Results/Conclusions:

The published methodology for using our composite stress fields in MABL updrafts and downdrafts (Sikora and Young 1993, 1994) provides the first-ever quantitative description of the planview patterns of air/sea flux of momentum; these patterns are suitable for forcing models of ocean waves and radar backscatter for the simulation of the kilometer-scale mottled convective signatures on SAR images such as those from ERS-I (Fig. 1; Sikora *et al.* 1995).

On a somewhat larger scale, analysis of ship observations and MM4 results suggest that a solenoidal circulation, dynamically akin to the classic sea-breeze circulation, causes the significant MABL wind variations observed in the vicinity of the northwest wall of the Gulf Stream (Fig. 2; Sublette 1994; Sublette and Young 1995). This common phenomenon is often revealed by a cloud line in meteorological satellite and HI-RES cruise observations, by the band of altered wind direction in the MM4 mesoscale model forecasts and in the RV Vernadsky and USNS Bartlet transects. Further modeling work on a finer horizontal grid is necessary to complete the description of this phenomenon, its effect on the sea-surface stress field, and the range of conditions under which it can occur.

Theoretical understanding of possible kilometer-scale stratocumulus–topped boundary layer responses also increased. The key result of this work (Laufersweiler 1993; Laufersweiler and Shirer 1994, 1995) is that for the same thermal forcing rates (air-sea temperature differences and cloud base layer stabilities), the boundary layer circulation may adopt one of two possible responses. The first response corresponds to the stratocumulus layer being decoupled from the subcloud layer, while the second response represents a boundary layer in which the subcloud layer and cloud layer periodically decouple and couple.

The preliminary results from the two- and three-dimensional models (Bromfield 1994; Lambert 1995; Shirer *et al.*, 1995) indicate that the stress variability patterns at the sea surface stress are reasonable, and agree qualitatively with those found by Gerling (1986) and Alpers and Brümmer (1994), who studied the SAR signatures produced by roll circulations in the MABL. These encouraging results were obtained only after a spurious source of energy at the lower boundary was eliminated using a method that did not require a second recoding of the model.

Impact for Science

These observational and modeling results have led to an improved understanding of some of the atmospheric causes of stress variability at the sea surface. Further work is needed before we can fully meet our second objective of identifying the environmental conditions that are necessary and sufficient for the formation of each of these buoyantly-driven circulations.

Relationships to Other Programs or Projects

The results obtained on this HI-RES ARI project nicely complement the studies of coherent structure types that are currently underway in our ONR-funded Marine Boundary Layer (MBL) ARI project. The coherent structures identified using conditional sampling by Sikora and Young (1993, 1994) are being examined using principal component analysis (PCA) of data from large eddy simulation (LES) and from observations being taken during the Danish experiment RASEX. Development of an improved tool for estimating the correlation dimension (Fosmire 1993; Fosmire *et al.* 1995; Wells *et al.* 1993, 1995) was begun on this HI-RES project and has continued within the MBL ARI to help us identify the intermittency associated with chaotic coherent structure types found using PCA. Finally, mesoscale modeling results from simulations of the solenoidal circulations observed along the Gulf Stream Wall during HI-RES have served as a foundation for a proposal by Profs. Nelson Seaman and George Young for a finer-scale examination of this and other mesoscale phenomena of the mid-Atlantic Bight as part of the Ocean Modeling, Atmospheric Modeling, and Ocean Optics Programs within the ONR Atmosphere/Ocean/ Space Department.

Transitions Accomplished or Expected:

Sikora et al. (1995) demonstrates the use of SAR imagery to diagnose boundary layer stability and depth, a capability that has many operational applications to radar propagation and the determination of the sign of the air/sea thermodynamic fluxes.

Report References:

Alpers, W. and B. Brümmer, 1994: Atmospheric boundary layer rolls observed by the synthetic aperture radar aboard the ERS-1 satellite. *J. Geophys. Res.*, **99**, 12613-12621.

Bromfield, P.J., 1995: Sea surface stress variability caused by boundary layer rolls. MS Thesis, The Pennsylvania State University, in preparation.

Fosmire, C.J., 1993: Estimating the correlation dimension of observed boundary layer winds. MS Thesis, Penn State University, 112 pp.

Fosmire, C.J., H.N. Shirer, and R. Wells, 1995: The chaotic structure of low frequency boundary layer time series. *Preprints, 11th Symposium on Boundary Layers and Turbulence,* Charlotte, NC, American Meteorological Society, in press.

Gerling, T., 1986: Structure of the surface wind field from seasat SAR. *J. Geophys. Res.*, **91**, 2308-2320.

Lambert, B. 1995: Sea surface stress variability in the marine atmospheric boundary layer. MS Thesis, The Pennsylvania State University, in preparation.

Laufersweiler, M.J., 1993: A theoretical model of multiple regimes in a stratocumulus-topped boundary layer. PhD dissertation, Penn State University, 69 pp.

Laufersweiler, M.J. and H.N. Shirer, 1994: Multiple regimes within the stratocumulus-topped boundary layer. *Preprints, Eighth Conference on Atmospheric Radiation*, Nashville, TN, American Meteorological Society, 256-258.

Laufersweiler, M.J. and H.N. Shirer, 1995: A theoretical model of multiregime convection in a stratocumulus-topped boundary layer. *Bound. Layer Meteo*, in press.

Shirer, H.N., L.V. Zuccarello, P.J. Bromfield, B.A. Lambert and R. Wells, 1995: Sea surface stress variability caused by kilometer-scale boundary layer circulations. *Preprints, 11th Symposium on Boundary Layers and Turbulence,* Charlotte, NC, American Meteorological Society, in press.

Sikora, T.D. and G.S. Young, 1993: Observations of planview flux patterns within convective structures of the marine atmospheric surface layer, *Boundary Layer Meteorology*, **65**, 273-288.

Sikora, T.D. and G.S. Young, 1994: Observations and applications of the horizontal perturbation wind field within convective structures of the marine atmospheric surface layer. *Boundary Layer Meteorology*, **68**, 419-426.

Sikora, T.D., G.S. Young, R.C. Beal, and J.B. Edson, 1995: Boundary layer convection in an ERS-I synthetic aperture radar image of the sea surface. To be submitted to *Mon. Wea. Rev.*

Sublette, M.S., 1994: Warm-season effects of the Gulf Stream on mesoscale characteristics of the atmospheric boundary layer. MS Thesis, The Pennsylvania State University, in preparation.

Sublette, M.S. and G.S. Young, 1994: An analysis of the Gulf Stream Atmospheric Front during the summer season. *Preprints, Sixth Conference on Mesoscale Processes*, Portland, OR, American Meteorological Society, 258-261.

Sublette, M.S. and G.S. Young, 1995: Warm-season effects of the Gulf Stream on mesoscale characteristics of the atmospheric boundary layer. *Mon. Wea. Rev.*, in preparation.

Wells, R., H.N. Shirer, C.J. Fosmire and J. Doran, 1993: Improved algorithms for estimating the correlation dimension and the associated probable errors. *Department of Mathematics Report No. 114*, Penn State University, 59 pp.

Wells, R., H.N. Shirer, and C.J. Fosmire, 1995: Extension and convergence of the Takens estimators for the correlation dimension. *Physica D*, submitted.

Zuccarello, L.V., 1994: Modeling sea-surface stress variability caused by kilometer-scale marine atmospheric boundary layer circulations. MS Thesis, The Pennsylvania State University, 64 pp.

PUBLICATIONS/PRESENTATIONS/AWARDS—FY93/FY94
HAMPTON N. SHIRER AND GEORGE S. YOUNG, PI
NOVEMBER 1994

Refereed Papers

Laufersweiler, M.J. and H.N. Shirer, 1995: A theoretical model of multiregime convection in a stratocumulus-topped boundary layer. *Bound. Layer Meteo*, in press.

Sikora, T.D. and G.S. Young, 1993: Observations of planview flux patterns within convective structures of the marine atmospheric surface layer, *Boundary Layer Meteorology*, **65**, 273-288.

Sikora, T.D. and G.S. Young, 1994: Observations and applications of the horizontal perturbation wind field within convective structures of the marine atmospheric surface layer. *Boundary Layer Meteorology*, **68**, 419-426.

Wells, R., H.N. Shirer, and C.J. Fosmire, 1995: Extension and convergence of the Takens estimators for the correlation dimension. *Physica D*, submitted.

Non-Refereed Papers

Fosmire, C.J., 1993: Estimating the correlation dimension of observed boundary layer winds. MS Thesis, Penn State University, 112 pp.

Laufersweiler, M.J., 1993: A theoretical model of multiple regimes in a stratocumulus-topped boundary layer. PhD dissertation, Penn State University, 69 pp.

Laufersweiler, M.J. and H.N. Shirer, 1994: Multiple regimes within the stratocumulus-topped boundary layer. *Preprints, Eighth Conference on Atmospheric Radiation*, Nashville, TN, American Meteorological Society, 256-258.

Sublette, M.S. and G.S. Young, 1994: An analysis of the Gulf Stream Atmospheric Front during the summer season. *Preprints, Sixth Conference on Mesoscale Processes*, Portland, OR, American Meteorological Society, 258-261.

Wells, R., H.N. Shirer, C.J. Fosmire and J. Doran, 1993: Improved algorithms for estimating the correlation dimension and the associated probable errors. *Department of Mathematics Report No. 114*, Penn State University, 59 pp.

Zuccarello, L.V., 1994: Modeling sea-surface stress variability caused by kilometer-scale marine atmospheric boundary layer circulations. MS Thesis, The Pennsylvania State University, 64 pp.

Number of Grad Students

Supported by HI-RES	3; 1 is a minority
Supported by HI-RES and MBL ARI	1
Supported by Air Force	2
Total	6

Patents

None

Presentations and Briefings

Shirer, H.N., R. Wells, P.J. Bromfield, L.V. Zuccarello, and B.A. Lambert, 1994: Sea surface stress variability caused by kilometer-scale boundary layer circulations Spring 1994 HI-RES Workshop, Ann Arbor, MI, May 1994

Shirer, H.N., R. Wells, H.W. Henderson, C.J. Fosmire, N. S. Winstead, 1994: Diagnosing chaotic behavior in boundary layer time series. Third Marine Boundary Layer Accelerated Research Initiative Workshop, Scripps Oceanographic Institute, La Jolla, CA, July 1994.

Sublette, M.S. and G.S. Young, 1994a: An analysis of the Gulf Stream Atmospheric Front during HI-RES. HI-RES Workshop, Ann Arbor, MI, May 1994.

Sublette, M.S. and G.S. Young, 1994b: An analysis of the Gulf Stream Atmospheric Front during the summer season. Sixth Conference on Mesoscale Processes, Portland, OR, July 1994, American Meteorological Society.

Young, G.S, 1993: Spatial variations in air/sea interaction: Observed phenomena and expected signatures. Hi-RES workshop, Woods Hole Oceanographic Institute, November 1993.

Young, G.S., 1994a: Meteorology of the convective boundary layer. Invited presentation at Woods Hole Oceanographic Institution, Summer, 1994.

Young, G.S., 1994b: Air/sea interaction in convective wakes. Invited presentation at Woods Hole Oceanographic Institution, Fall 1994.

Young, G.S., 1994c: Meteorology of thunderstorms. Invited presentation at Woods Hole Oceanographic Institution, Fall 1994.

Young, G.S., 1994d: Statistical approaches to quantifying coherent structures (RASEX). Invited presentation at Risø National Laboratory, Roskilde, Denmark, Fall 1994.

Young, G.S. and H.N. Shirer, 1993: Contributions of coherent structures to intermittency of air/sea fluxes. Second Marine Boundary Layer Accelerated Research Initiative Workshop, Scripps Oceanographic Institute, La Jolla, CA, March 17, 1993.

Young, G.S., D.K. Rinker, T.D. Sikora, 1994: Coherent structure identification using obliquely rotated principal component analysis. Third Marine Boundary Layer Accelerated Research Initiative Workshop, Scripps Oceanographic Institute, La Jolla, CA, July 1994.

Awards/Honors

H.N. Shirer, co-PI

Promoted to Associate Head of the Department of Meteorology, October 1, 1993.

T.D. Sikora, Graduate assistant (also supported by MBL ARI)

Elected Graduate Student Senator, University Senate, (August 1993 to present)

Elected Departmental Graduate Student Association Representative (August 1992 to present)

NSA/AMS travel scholarship to attend 74th AMS Annual Meeting in Nashville, TN (January, 1994)

G.S. Young, co-PI

Awarded sabbatical leave for '94-'95 academic year; majority of time to be spent at Risø National Laboratory, Roskilde, Denmark, in part to collaborate on MBL ARI-funded RASEX field project

Committee or Panel Service

H.N. Shirer, co-PI

Associate Editor, *Journal of the Atmospheric Sciences*, August 1992-December 1993.

T. D. Sikora, Graduate assistant (also supported by MBL ARI)

Session chair, Fifth Symposium on Global Change Studies, AMS, Nashville, TN

Mission forecaster and mission scientist for one IOP day during the April 1994 Atmospheric Radiation Program field project

G.S. Young, co-PI

TOGA Surface Processes Group (1991-present)
UCAR University Relations Committee (1991-1994)
Mountain Meteorology Committee (1992-present)
ASTEX Science Team (1992-present)